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An In-depth Review of the Critical Water Analysis Parameter and Water Quality Management Technology in Cage Aquaculture within Malaysian Coastal Regions

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ABSTRACT

Cage fish farming in Malaysia's coastal areas is a significant industry that provides food and income for local communities. Since the country's catch-fishing resources have been fully exploited, there is a huge market for developing the aquaculture industry to increase fish output and supply. However, disease outbreaks, pollution, and environmental degradation must be addressed to ensure sustainable and environmentally responsible practices. This can result in increased stress levels and susceptibility to diseases, ultimately impacting the overall well-being of fish populations within the aquatic ecosystem. Water quality plays a crucial role in fish farming as it significantly impacts the health and productivity of fish. However, the specific critical water analysis parameters that are most relevant to cage aquaculture in Malaysian coastal regions have not been comprehensively identified and defined, leading to uncertainties in monitoring and managing water quality. In the past, water quality detection needed manual sampling and laboratory analysis, which were time-consuming and resource intensive. This traditional approach cannot deliver real-time data. This literature examines the important water analysis parameters and contemporary technology that has the potential to be adopted by fish farmers in Malaysia and addresses the financial implications of such an adoption. The review protocol started by selecting the relevant literature and several important things were considered during the selection process. The identification and definition of critical water analysis parameters emerge as fundamental to effective water quality monitoring and management in cage aquaculture. By delineating these parameters, we can tailor monitoring strategies using recent technologies to the unique environmental conditions of Malaysian coastal regions, thus enabling more precise interventions when deviations occur.

Keywords: Water quality, Fish Farming, Coastal area, Water Analysis, Aquaculture Technology

INTRODUCTION

Overall, cage fish farming in coastal areas has played an important role in Malaysia's aquaculture industry, providing a source of income and food for local communities (Iliyasu et al. 2016; Kamaruddin & Baharuddin 2015; Yusoff 2015). However, it is essential to ensure that farming practices are sustainable and environmentally responsible for protecting the long-term health of the marine ecosystem. The choice of fish species for cage fish farming depends on various factors such as environmental conditions, market demand, and local regulations. Some commonly farmed fish species suitable for cage aquaculture include tilapia, catfish, salmon, trout, and carp. However, the suitability of a specific fish species may vary depending on the region and specific goals of the fish farming operation. Marine finfish such as groupers, snappers, and seabass are commonly farmed in Malaysia (Fisheries 2020; Kamaruddin & Baharuddin 2015; Muhammad 1993). Cage farming involves using floating cages anchored to the seabed or fixed building. The fish are grown in a controlled environment and fed by commercial feed and locally available sources such as trash fish or seaweed (Alongi et al. 2003; Yusoff 2015).

According to the Department of Fisheries Malaysia, cage farming is growing, with cages increasing from 1,620 in 2000 to 8,522 in 2019 (Malaysia 2019). The industry has been supported by government initiatives such as the National Aquaculture Development Plan, which aims to increase seafood production through sustainable aquaculture practices (2021-2030, 2021). However, cage farming in coastal areas also faces several challenges, including disease outbreaks, pollution and environmental degradation (Din & Ahamad 1995; Mahboob 2013). To address these issues, the Government has implemented regulations and guidelines for cage farming. For example, the Department of Fisheries Malaysia has established a code of conduct for cage farming that covers cage design, stocking density, and feed management (Malaysia 2009).

Research on cage fish farming in Malaysia has also been conducted, with studies focusing on topics such as fish growth and survival, water quality management, and disease control. For example, a study by Hai, N. V. (2015) published in the Journal of applied microbiology found that using probiotics in feed can improve the growth and survival of fish in cage culture (Hai 2015). Another study by P. A. Devi et. al (2017) highlighted the importance of monitoring water quality parameters such as temperature, dissolved oxygen, and pH in cage farming systems to prevent disease outbreaks and optimize fish growth (Devi et al. 2017).

There are several environmental issues related to fish farming in Malaysia, including pollution, where fish farming can generate waste, such as uneaten feed and fish excrement. This can pollute surrounding water bodies if not properly managed (Environment 2011; Price et al. 2015). The second issue is disease outbreaks. Fish farming in polluted conditions can spread diseases that can affect both farmed and wild fish populations (Holmer 2010). This literature extensively examines specific critical water analysis parameters that are most relevant to cage aquaculture in Malaysian coastal regions that have not been comprehensively identified and defined, leading to uncertainties in monitoring and managing water quality. The parameters encompassed in this category consist of pH, dissolved oxygen (DO), biological oxygen demands (BOD), turbidity, total suspended solids (TSS), nitrite, nitrate, and ammoniacal oxygen. The present study examines the various water quality monitoring technologies considering the essential criteria. The successful deployment of these technologies will be contingent upon factors such as cost considerations and the appropriateness of the geographical location. Challenges related to technology adoption, including financial constraints, lack of knowledge, and access to advanced equipment, hinder the widespread use of water quality management technologies in Malaysian cage aquaculture.

MATERIAL AND METHOD

This section discusses the criteria for the in-depth review of critical water analysis parameter and water quality management technology in cage aquaculture. The study focused more on Malaysian coastal regions as the region of interest. The review protocol started by selecting the relevant literature. Several important things were considered during the selection process: the only article in English, the match with keywords, and the research type of publication. Several combinations of keywords were used in the search process: Water quality, Fish Farming, Coastal area, Water Analysis, Aquaculture Technology. Initialisation of the searched material assessed the article based on the title that matched the mentioned search keywords. In addition, a manual search was also carried out based on a reference list, which was not found by initially electronic searching. The selected papers were then divided into category clusters: Malaysia cage farming, the effect of pollution on cage farming, water quality analysis, and water quality monitoring.

Further assessment proceeds by analysing the abstract and excluding the irrelevant papers. A total of 205 potential related research articles were identified based on the title and abstract assessment process before further full-text reading. Two reviewers were assigned for each category cluster to avoid bias during the full-text reading, and the evaluation process can be carried out smoothly. After duplication, only 47 articles were finalised as they meet the current research requirements. The flow process is illustrated in Figure 1.

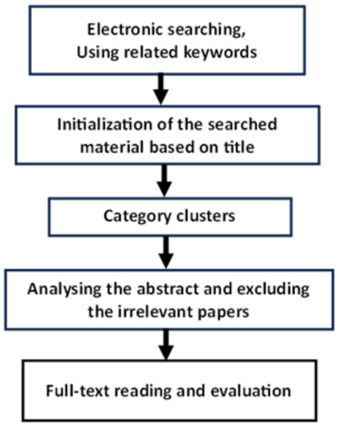

FIGURE 1. The flowchart of the methodology used.

CAGE FISH FARMING INDUSTRY IN MALAYSIA

FISH FARMING LOCATION AND FARMING STATISTICS IN MALAYSIA

Malaysia is surrounded by rivers and lakes and is bordered by the sea. These critical ecosystems supply natural fisheries and other aquatic resources for those living there. As a result, Malaysian cuisine has a long-standing tradition of incorporating fish as a staple, providing a significant source of protein for the population. Cage fish farming is located in various coastal areas of Johor, Malaysia. Some major locations of cage fish farming in Johor include Tanjung Piai, Pontian, Kukup, and Sungai Pulai (Chor et al. 2022; Mohamat-Yusuff et al. 2015; VC & Sasekumar 2002). However, it is important to note that the specific areas and the number of cage fish farms may vary over time due to various factors such as government regulations, environmental conditions, and market demand. According to the "Johor State Agriculture Department," cage fish farming is mainly located in the coastal areas of Johor, particularly in the districts of Mersing, Kota Tinggi, and Pontian. The department has identified these areas as potential development zones for cage fish farming due to their favorable environmental conditions, such as suitable water quality and tidal flows. The choice of a good location is one of the most important parts of setting up a cage culture system. A good site will help fix a lot of the problems with how the culture system is run. When looking for places to put floating cages, the most important things to look for are good water quality, enough water exchange, and safety from animals and natural dangers. When engaging in coastal cage culture, it is imperative to consider certain factors. These include the current speed at the chosen places, the direction and speed of prevailing winds, as well as the potential impact of hurricanes, typhoons, and strong tidal waves on the selected sites (Hasim et al. 2017).

Cage fish farming is categorized under the aquaculture industry. In 2020, Malaysia's aquaculture business produced 400,017 metric tonnes worth RM3.6 billion, accounting for 22% of the country's total fisheries production. Compared to 2019, this industry has experienced a decline in production, with a 2.9% loss in quantity and a 5.7% decrease in value. Brackish water culture generated around 75% of aquaculture productivity, with seaweed production accounting for 46% of the total output at 182,061 metric tonnes valued at RM58 million. Other brackish aquaculture species such as shrimp, fish, and shellfish contributed 120,746 metric tonnes worth RM2.28 billion, accounting for 30% of the total. Meanwhile, freshwater aquaculture commodities accounted for 24% of the total 97,210 metric tonnes worth RM766 million produced (Fisheries 2020). Aquaculture development has considerable potential for commercial growth to improve the production and supply of fish in the country, as catch fishing resources have reached their maximum degree of exploration.

The Aquaculture Integration Development Program (Integrated Cage System) is a plan by the Department of Fisheries Malaysia to support aquaculture production in the country during the implementation period of 2021-2025, which is part of the 12th Malaysia Plan - a national development plan. To provide support, the Malaysian Government offers incentive assistance through the Department of Fisheries Malaysia to cover operating costs during the breeding period until revenue from sales is obtained as a partial return on investment for both the private sector and the community. The Aquaculture Integration Development Program (Integrated Cage System) targets the private sector and communities operating aquaculture through fish cage systems for freshwater and marine fish. A caged Fish Breeding System is not limited to shape, size, and type as long as it can be known as the Caged Fish Breeding System. The Department of Fisheries Malaysia has set a target to achieve the cumulative production of revenue obtained through the Aquaculture Integration Development Program by 31 December 2025, a 15,000-tonne metric of livestock. It generates 2,500 jobs directly and indirectly with the project.

Due to the strong support from the Government of Malaysia, the aquaculture industry has grown rapidly. Many potential cage farming areas have grown across Malaysia, as shown in Figure 2. By 2020, the total number of cage fish farmers has grown to 1963 persons, with 30,416 cages. This has resulted in a total fish cage area of 550,037 m2 in Malaysia. Among all states in Malaysia, Pahang and Sarawak, with 11794 and 10445 units, respectively, have the most fish cages set up, as shown in Figure 3. The cage fish farming business produced 48679.61 metric tonnes of fish, with brackish water accounting for 68% of the value and freshwater accounting for 32% (refer to Figure 4). According to Figure 5, Penang, Perak, and Pahang produce the most fish cages, with 18,711.76, 9602.96, and 8473.57 metric tonnes produced in each state (Fisheries 2020).

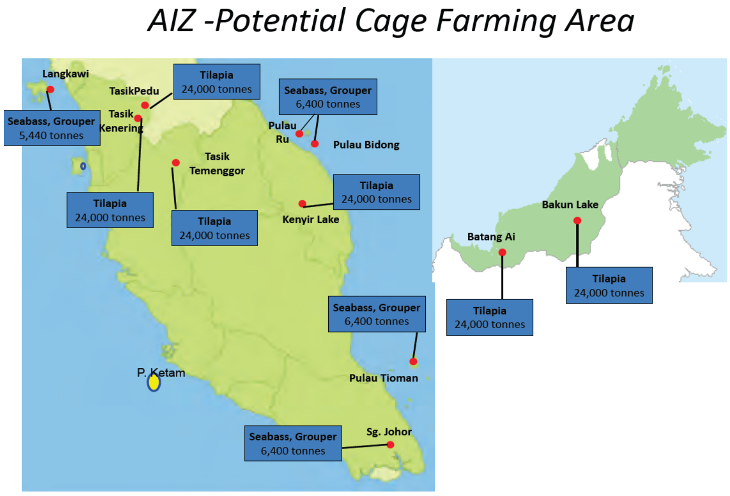

FIGURE 2. Potential Cage Farming Area across Malaysia

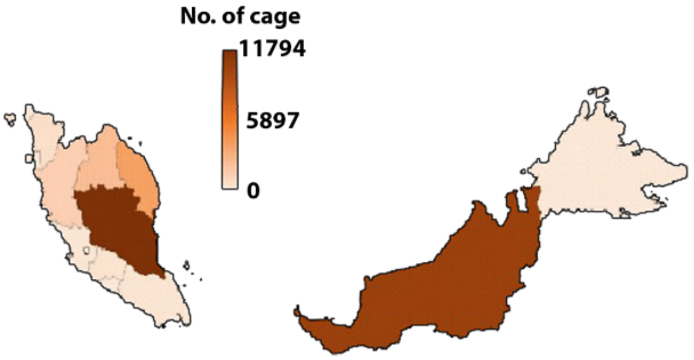

FIGURE 3. The number of cages across Malaysia

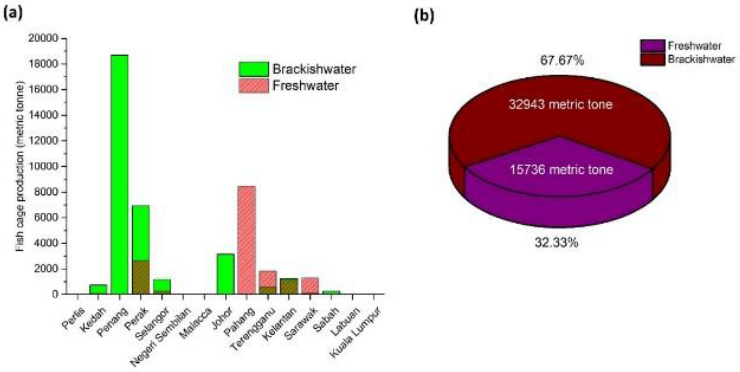

FIGURE 4. (a) Fish cage production by state (in metric tonne) (b) Fish cage production (in metric tonne)

FISH CAGE DESIGN AND RELATED TECHNOLOGY

The growth of salmon farming in Norway in the 1970s set the standard for marine commercial cage culture. In Asia, cage farming in inshore and brackish waterways is relatively recent. Asia has diverse species and culture intensities for marine and brackish water cage farming. However, managing cage farms remains a major challenge in the continuous expansion and improvement of small-scale cage culture in many Asian countries. Due to a shortage of artificial breeding technologies, China, the largest fish exporter in Asia, faces issues with cage finfish aquaculture breeding technology and culture. Improving production efficiency through effective management and culture systems can increase the production of cage cultures. Feed management in Malaysia is challenging due to a lack of skills and knowledge among cage farmers, which account for the major costs of cage fish farming. Further research on formulated feed can increase the growth of cultured fish and save time in the culturing period. Providing extension and training to cage farm owners/managers on the importance of quality seeds and reducing feed costs can enhance their skills and knowledge, increasing technical efficiency and productivity in cage farms.

In Malaysia, fish seeds will be maintained in enormous river cages or abandoned mines. For this purpose, iron and netting cages are frequently utilised. The cage's frame is made of iron, which is more durable than wood when submerged in river water for an extended period. A net will be constructed around the outside and at the bottom of the cage based on the size of a specific hole that can accommodate the fish quantity without enabling the fish to escape. These nets are also used to allow river water to flow almost naturally. These cages will be placed on a raft made up of a buoy network. Because of this, these cages will constantly be floating in the raft, which will always be dangling from the raft. As the water level in the river recedes or rises, the raft will always follow the river's surface level, and the fish in the cage will always be in the water without touching the river's bottom.

The behaviour of the cultured species dictates the cage design. Greater net space is needed for pelagic species like the jack (Carangoides) and threadfin bream (Polynemidae), known for their constant surface swimming. These fish frequently congregate in shoals and swim continuously in circles. Hence, circular or hexagonal cages may be more suitable than rectangular or square cages. The movement of demersal fish such as groupers (Serranidae) and marble goby (Gobidae), which are not territorial and prefer to seek refuge under any underwater structures, is minimally affected by the shape of the cages. Due to their simplicity, square or rectangular cages have an advantage over circular or hexagonal ones in terms of ease of construction, management, and assembly.

There are several sizes of cages used for fish farming. The 4'x 6', 8'x 10', and 10'x 12' are among them. In minor rivers or the ruins of disused mines, 4'x 6' cages are commonly employed. This cage size is sufficient for 500 to 600 fish per cage. Cages measuring 8'x 10' and 10'x 12' are widely utilised in Sungai Pahang. This is due to the vastness of the Pahang River, which allows for this measurement. The specific number of fish per cage is 1500 to 2000. In Sungai Pahang, cage fish farmers often use cages that measure 8'x 10' because they are easy to operate. According to a study, the average size of cages was 1127 m2, and cage farms were relatively more prominent in Perak (2159 m2) compared to the Johor area (902 m2) (Islam et al. 2016).

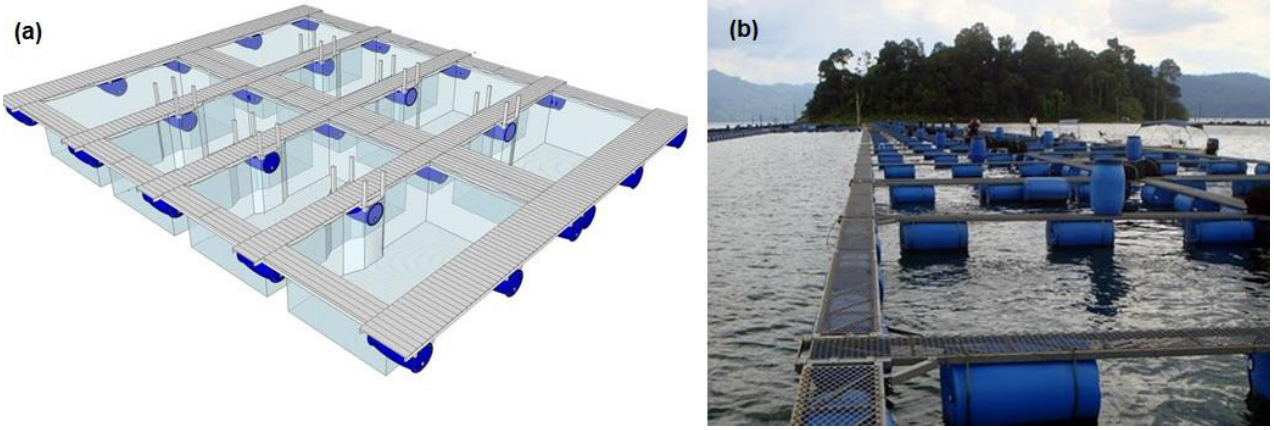

FIGURE 5. (a) An example of a fish cage drawing design (b) The fish cage used in the brackish water area

EFFECT OF POLLUTION ON FISH FARMING INDUSTRY

One important factor related to water pollution that needs to be considered is local water quality capable of fish farms constantly supplying high-quality fish to consumers. Based on the Department of Environment (DOE), water pollution is evaluated by suspended solids, biochemical oxygen demand, and ammoniacal nitrogen, the level of this pollution index that increased significantly from 2010 to 2014 (Islam et al. 2016). Besides that, contamination by heavy metals also affected the aquatic environment. It is reported that water is polluted with heavy metals because fish contain higher amounts of mercury and arsenic, which are not safe for consumption.

Water quality is an essential part of fish farming, contributing to fish health and production rate. Besides that, it is one of the factors of fish health that a decline in water quality could harm the fish, consequently causing stress and leading to disease as it accumulates in the aquatic ecosystem. Moreover, a significant increase in the demand for fish globally encourages the fast-growing farming industry to cope with food security worldwide. Thus, any effect on the quality brings a negative impact not only to the fish farmer but also on the consumers. One factor that affects water quality is water pollution, which could be caused by fertilizer run-off from the farming area, Oil spills or leaks, Chemical discharge, and dumping of domestic waste into the water. For example, toxic pollution from illegal poisonous waste dumplings in Pasir Gudang, Malaysia, in 2019 affected many parties and contributed to water quality pollution in surrounding areas (Yap, et al. 2019).

The sustainability of fish farming depends on much to water quality. It includes dissolved oxygen, temperature water pH reading, turbidity, and chemical content. This farming method is an alternative to providing the community with a food supply, especially for protein. Increasing water temperature induces stress on the fish and influences the animal's metabolism, which then affects the growth of the fish. In cage conditions, the suitable temperature of tropical species is 26-32°c (Loka 2015). Fluctuating the temperature could affect fish growth and causes industry losses. Besides that, the hydrogen ion index (pH) is important to monitor in the industrial area as it represents the pollution level. This pH value relates directly or indirectly to other parameters like water salinity, temperature, dissolved oxygen, and chemical content. The recommended value for fish production is 6.5-9.0 (Wurts & Durborow 1992). For the cases of high pH value, alkaline fish may show the effect of damage to the gill, eyes, and outer skin.

EFFECT OF POLLUTION ON THE FISH

As mentioned in the previous section, contamination can be from suspended solids, chemicals, and heavy metals (Chou, 2006; Mahat et al. 2018). This aspect affects fish farming, like the growth rate and welfare, or in the worst case, causes death as these harms the internal organ or causes a reduction of oxygen content in the water, making it hard for fish to breathe. Furthermore, fish deformities could happen if the pollution effet fish larvae, which causes significant losses at the beginning of the farming process, reducing the affected fish's survival (Sfakianakis et al. 2015). Pollution affects the fish in several parts of the body, the vertebral column, the fins, the air bladder, and the sensor organ of the lateral line. The most common effect reported is the vertebral column, which is classified as lordosis, which is extreme curvature of the lumbar part of the spine, kyphosis, and scoliosis.

Fish farming is treated by water pollution, and its vulnerability introduces stress to the fish. One of the stresses caused by pollution is oxidative stress (Mahboob 2013; Stoliar & Lushchak 2012). It is a situation where a lack of balance happens between the production of reactive oxygen species (ROS) and the antioxidant deference system of the fish. The effect is induced by heavy metal pollution and becomes highly toxic at high concentrations. Fish trap these heavy metals through the gill to extract oxygen during breathing, body surface, and digestion organ as they interact with polluted water. Oxidative stress will disturb the cellular metabolism of the fish and causes cell damage. Besides, an increase in ROS could affect the oxidation of the proteins and alteration in gene expression. This issue was highlighted in several studies carried out in several locations in Malaysia, one of them in Johor. Even though the level of heavy metal is still accepted according to Mohamat-Yusuff et al. (2015) as the study investigates the profile of heavy metal level of fish from Kong Kong Laut, Johor, their study suggested pollution may affect the area in the future (Mohamat-Yusuff et al. 2015). In 2020 study done by Ahmed JM et al. the mean concentration of vanadium is the highest found at Sungai Tiga Johor, where the area involves agricultural activities that potentially affect the fish farming product (Ahmed et al. 2011).

Even pollution causes harm to fish farming. In the same cases, it encourages the growth of clams found in Malaysia's coastal area (Hossen, Hamdan, & Rahman, 2015; Mahat et al. 2018). The animal consumes the metal enrich particle directly with less effect on its welfare. The concentration is different, but coastal areas, especially Kampung Pasir Putih, Johor, are among the highest level of pollution for clam species, indicating its pollution index that needs to be aware.

Another study done by Asmal et al. emphasised that inadequate management of grey water also played a role in the contamination of coastal regions. The unregulated disposal of greywater into various environments, such as beaches, highways, and yards, without prior treatment, poses potential risks to both the natural environment including fish farming ecosystem. This study elucidates that the continual discharge of greywater has an environmental consequence, namely the diminishment of soil absorption and water retention capacity. Greywater is the term used to describe the portion of household wastewater that does not include any faecal matter. The main sources of greywater consist of the discharge from laundry activities, bathing, and kitchen drainage. Greywater is characterised by elevated levels of biodegradable organic substances and various constituents originating from household activities. These constituents include nutrients such as nitrate and its derivatives, phosphorus and its derivatives, as well as xenobiotic organic compounds (XOCs). Additionally, greywater may contain biological microbes such as faecal coliforms, salmonella, and other common hydrochemical constituents (Asmal et al. 2022).

WATER QUALITY ANALYSIS

Malaysia promotes aquaculture as a significant economic driver that will eventually support the entire country's economy (Ismail et al. 2020). However, a vital component of any aquaculture system is water quality. Water quality is a crucial factor in the success or failure of an aquaculture operation, as it dramatically affects fish health. Any decline in water quality causes stress to fish and leads to diseases. Each factor linked to water quality interacts with and influences the other parameters, simultaneously offering vital insights into the resources essential for supporting life within the ecosystem. The quality of these water resources depends on numerous physico-chemical parameters.

Study of the temperature, pH, dissolved oxygen (DO), biological oxygen demands (BOD), turbidity, total suspended solids (TSS), nitrite, nitrate and ammoniacal oxygen has been taken place by previous researchers in Malaysia. Factors such as temperature and total suspended solids (TSS) determine the equilibrium structure of the marine ecosystem, while pH, dissolved oxygen (DO), and water nutrients are chemical characteristics that impact the physiological functions of aquatic organisms (Devi et al. 2017; Toha 2008). Nitrate, nitrite, and ammoniacal nitrogen are nutrients that can be introduced into the water through various sources. The high levels of these nutrients in water can be toxic to fish and lead to environmental degradation (Nyanti et al. 2012; Sing Ong et al. 2017). Nonetheless, the examination of chemical oxygen demand (COD) has been omitted from this review since it is primarily employed in the context of wastewater treatment and industrial applications. It is worth noting that all coastal waters in Malaysia, specifically for fisheries, are categorized as Class II according to the Malaysian Marine Water Quality Standards, indicating a low level of COD. In future, will suggest studying some key parameters including hardness, alkalinity, phosphate, and sulphate test the sensitivity towards the water quality.

The water quality parameters for several aquaculture sites in Malaysia are displayed in Table 1. The temperature of the water controls all aquatic life. Fish production is significantly impacted by temperature, one of the most important external factors affecting every biological and chemical process in an aquaculture operation (Devi et al. 2017). All Malaysian Coastal cage fish farming studies reported a water temperature range between 25.2 – 32.2 °C (Chor et al. 2022; Nyanti et al. 2012; Ong & Ransangan 2017; Razali et al. 2021), representing the best condition for tropical aquaculture species. The tide caused the variation in temperature, rainfall, and direct sunlight at the sampling time, which impacted the temperature (Razali et al. 2021; Suratman et al. 2016). A pH range of 6.5 to 9.0 is suitable for most freshwater species, but since marine species generally cannot tolerate as wide a pH range as freshwater species can, the suggested pH range for aquaculture in Malaysia is 7.5 to 9.0 (Ismail et al. 2020). A study at Kukup Strait in Johor, Malaysia, had a pH value of 6.7 to 7.8 and a pH of 6.97 at Batang Reservoir Cage Culture, Sarawak (Chor et al. 2022; Nyanti et al. 2012). According to Nyanti et al. (2012), decomposing organic matter, particularly from vegetation that was not removed before impoundment, and contributions from feed and cage culture waste caused the pH to fall as the depth of the water body increased (Nyanti et al. 2012). Other Malaysian studies found that the pH was regularly above neutral and was considered ideal. If below, some species may grow slowly, fail to maintain their salt balance, and have problems reproducing (Ong & Ransangan 2017)

DO is a crucial measure for determining water quality since it represents the physical and biological processes occurring in the water (Devi et al. 2017). Saturation levels should typically be at least 5 mg/L. According to Chor et al. (2022), Sing Ong et al. (2017), and Nyanti et al. (2012), dissolved oxygen (DO) levels in aquaculture sites varied from 5.50 to 6.00, 6.60 to 6.80, and 0.26 to 8.45 mg/L (Chor et al. 2022; Nyanti et al. 2012; Ong & Ransangan 2017). The depletion of DO in some areas can be attributed to microbial activity during the decomposition of organic matter (Law & Law 2020), while higher DO levels were observed during the rainy season due to increased water mixing from strong winds and rainfall (Law & Law 2020). An optimal DO level is essential for promoting growth and achieving high crop yield in aquaculture (Anusuya Devi et al. 2017) (Devi et al. 2017). However, there is limited research on aquaculture's biochemical oxygen demands (BOD) and chemical oxygen demands (COD) in Malaysia, apart from the physical parameters mentioned. Nyanti et al. (2012) recorded that Mean BOD ranged from 8.3 to 11.3 mg/L at Batang Reservoir, Sarawak (Nyanti et al. 2012). Then, according to Law & Law (2020), Bengoh Reservoir in Sarawak has a current BOD loading rate of

0.308 tons/day, which is attributed to the buildup of nutrients, organic matter, and waste from fish and leftover feed, particularly near the bottom of cage aquaculture sites (Law & Law 2020). The decomposition rate tends to increase as the water temperature rises during the dry season, as reported by Law & Law (2020) and Nyanti et al. (2012) (Law & Law 2020; Nyanti et al. 2012).

The turbidity parameter has not been extensively studied because it solely describes the qualitative appearance of water quality. Thus, TSS measured the quantity of erosion that occurred nearby or upstream. According to IMWQS, the Malaysian fish farming industry's acceptable level of TSS is less than 50 mg/L. Nyanti et al. (2012) and Sing Ong et al. (2017) ranged TSS from 1.50 - 9.10 and 0.05 ± 0.02 mg/L, respectively (Nyanti et al. 2012; Ong & Ransangan, 2017). However, Razali et al. (2021) recorded that TSS was higher than the IMWQS in June and September 2016, ranging from 2.00 ± 0.01 to 117.3 ± 4.16 mg/L. Large amounts of suspended particles will prevent light from penetrating the water, inhibiting phytoplankton, algae, and macrophyte photosynthetic activities. Fish waste and too much fish feed contributed to the cage culture site's higher TSS value (Boyd, 2004).

Next, Nyanti et al. (2012) and Sing Ong et al. (2017) conclude that most inorganic nitrogen, such as nitrite (NO2-), nitrate (NO3-), and ammoniacal-Nitrogen (NH3-N) in coastal cage fish is slightly higher than in open sea due to faeces released by the fish. When there is no water flow through the cage, the high fish densities and rapid feeding rates frequently cause dissolved oxygen levels to drop and ammonia concentrations to rise within and outside the cage. Sing Ong et al. (2017) recorded NO3-, NO2-, and NH3-N of 80.5 - 989.9, 0.2 – 2.3, and 27.8 – 64.2 µg/L, respectively. Razali et al. (2021) showed that the value of NO3- and NO2- is up to 180 and 80 µg/L (Razali et al. 2021). In conclusion, aquaculture has affected water quality, and a monitoring program should be implemented to detect problems early and protect Malaysia's aquaculture industry.

TABLE 1. Water Quality Parameters for Malaysian Cage Fish Aquaculture Locations

Water Quality	INWQS Class II (DOE 2011)	Location of cage fish aquaculture in Malaysia				
		Ambong Bay, Sabah (Sing Ong et al. 2015)	Kukup Strait, Johor (Chor et al. 2022)	Sungai Udang, Penang (Razali et al. 2021)	Batang Ai Hydroelectric Dam Reservoir, Sarawak (Nyanti et al. 2012)	Bengoh Reservoir, Sarawak (Law & Law 2020)
Temperature	≤ 2°C increments	30.0-33.2	29.3-30.2	29.00±0.01-32.39±0.09	25.2-32.2	NA
pH	6.5 – 9.0	7.45–8.07	6.7-7.8	7.37±0.05-8.57±0.06	6.97	NA
Dissolve oxygen (DO)	>5.0 mg/L	3.12–6.60	5.5-6.0	2.36±0.04-9.18±0.20	0.26–8.45	NA
Turbidity	NA (NTU)	NA	NA	3.07–93.70	0.019–0.057	NA
Total suspended solids (TSS)	50 mg/L	0.018–0.267	NA	2.00±0.01-117.3±4.16	1.50–9.10	NA
Nitrite (NO_2^-)	55 µg/L	0.2–2.3	NA	0–80	NA	NA
Nitrate (NO_3^-)	60 µg/L	80.5–989.9	Up to 383	0–180	NA	NA
Ammoniacal-nitrogen (NH_3^-N)	50 µg/L	27.8–64.2	3 and 179	NA	NA	NA
BOD_5	NA (mg/L)	NA	NA	NA	6.80-13.86	0.308 tons/day

WATER QUALITY MONITORING

Water is essential for the survival of agriculture, industry, living organisms, and human beings. Malaysia is one of the top 15 global producers of aquaculture production. However, with the increasing presence of various sources of pollution and contamination, monitoring water quality has become increasingly important. In Peninsular Malaysia, the Department of Environment has identified 2,292 industries as significant water pollutant sources, including 40% of food and beverage factories, 14.1% of rubber-producing premises, and 11.4% of chemical producers. Therefore, it is crucial to continuously monitor water quality, as any deviation from the permitted parameters can result in adverse outcomes such as disease, stress, death, and financial loss. In the past, water quality detection was conducted manually by taking water samples and analyzing them in laboratories, which was both time-consuming and required a significant number of resources (Das & Jain 2017). However, this traditional method cannot provide real-time data. A water quality monitoring system with a microcontroller and basic sensors has been proposed to overcome this limitation. This compact system can detect pH, turbidity, water level, temperature, and humidity and wirelessly send continuous and real-time data to a monitoring station (Sugapriyaa et al. 2018).

Wireless sensor networks (WSN) are a proposed solution for water monitoring systems, consisting of data monitoring nodes, a database station, and a remote monitoring center. These systems suit complex and large-scale water environments such as reservoirs, lakes, and rivers. They utilize high-power transmission Zigbee-based technology and IEE E 802.15.4 compatible transceivers for impromptu or continuous monitoring. The WSN uses three types of sensors: a pH sensor to measure water acidity or basicity, a temperature sensor, and a turbidity sensor based on a phototransistor. The sensors operate on batteries, and a signal conditioning circuit conditions the electrical signals produced by the sensors to ensure they are proportional to the actual parameter values. The microcontroller or microprocessor then processes the signal to make it understandable to humans, as illustrated in Figure 6 (Rasin & Abdullah 2009).

Sensor nodes can measure and monitor various in-situ environmental parameters, such as water temperature, salinity, turbidity, pH, oxygen density, and chlorophyll levels. The collected data can be transmitted to sink nodes through wireless communication protocols like ZigBee. Communication between sensor nodes and a sink node is typically point-to-point. The sink node then collects and transmits data from sensor nodes to the base station via the GPRS network. The server processes and stores the data from the base station, and user terminals can access the server over the Internet, as illustrated in Figure 7 (Xu et al. 2014).

The Internet of Things (IoT) has recently made water monitoring systems more advanced. In-pipe water samples can be tested using IoT, and the collected data can be uploaded to the Internet. When water quality parameters have deviated from a pre-defined set of standard values, the system can provide an alert to a remote user. The flow of the water quality monitoring system with IoT is illustrated in Figure 8 (Geetha & Gouthami 2016).

A real-time water monitoring prototype incorporates multiple turbidity, temperature, flow, and pH sensors into one system, as shown in Figure 9. The system is divided into a data collection subsystem comprising the sensors and microcontroller and a data management and notification subsystem consisting of the software, application, and display devices. Typically, the sensors and Arduino controller are employed and connected with IoT. Arduino is an open-source software utilized for constructing electronics projects. It encompasses a physical programmable circuit board or microcontroller and an IDE (Integrated Development Environment) software that runs on a computer to write and upload code to the physical board. The microcontroller in Arduino evaluates and routes the digital information to the data management subsystem available, such as a GPRS/GSM module. The GSM model sends the water quality parameters to the smartphone/PC via SMS, which can be viewed on the LCD.

A different water monitoring system has been proposed, which allows for the integration of locally available sensors to detect water quality factors in real-time and to use various water filters to enhance water quality. The system uses an Arduino microcontroller and IoT integration to eliminate the inconvenience and time consumption of offline lab analysis. The system can also warn users of rejected water unsuitable for consumption, improving public health and cost control. The integrated IoT components can decide real-time values and record trends based on historical data. The system sends rejected water to the filter and consumes accepted water. The system is shown in Figure 10 (AlMetwally et al. 2020).

Several mobile applications are available for water monitoring purposes. For instance, Blynk is an application that allows end-users to obtain results instantly via a smartphone. It provides interfaces for controlling and monitoring hardware projects from iOS and Android devices. The end-user can create a project dashboard and arrange widgets on the screen. Blynk's app is often used to control the Arduino software remotely. Another open-source IoT application that can store and retrieve data from sensors is ThingSpeak. It can be accessed using Local Area Network (LAN) or HTTP. It offers features such as sensor logging, location tracking, and a social network of things with status updates.

One available application for water monitoring is the Python PyCharm IDE software, which utilizes the Python data analysis modules to analyze and visualize data. Two experiments were conducted using a water monitoring system integrated with the PyCharm IDE software. The first experiment used standard and well-known quality solutions to determine measurement accuracy. In contrast, the second experiment involved adding specific contaminants to clean water to measure and record quality parameters over an extended period. Other mobile applications suitable for water monitoring include Blynk, which provides interfaces for controlling and monitoring hardware projects from iOS and Android devices, and ThingSpeak. This open-source IoT application can store and retrieve sensor data using LAN or HTTP over the Internet.

The user of the Python PyCharm IDE software can determine the minimum-maximum range of the PH (3.1 – 5.5), turbidity (4.99 – 97.7 NTU), and temperature (21-21°C) directly from the software without manually taking the water sample at the local station. The means parameter value can be obtainable, and tracking activity also can be performed. The modern technology of the water monitoring system helps users get instantaneous information and, at the same time, revert the action quickly if any uncertainty occurs. The adaptation of this modern technology could save costs and time effectively.

POTENTIAL WATER MONITORING TECHNOLOGIES IN MALAYSIA

The implementation of effective water quality monitoring can be facilitated by the extensive updating of technology and the availability of reliable internet access in Malaysia. Farmers can use the real-time sensing system, known as the Arduino Uno, as the microcontroller. They can start with basic sensors, which include a pH sensor, a turbidity sensor, and a conductivity sensor. The Wi-Fi module can be used to transmit the outcomes to the mobile device through a Wi-Fi connection. There are a lot of Wi-Fi providers in Malaysia that can offer highly affordable prices. The results were transmitted via the Blynk software platform for analysis and interpretation. With easy access to their mobile phones, farmers can check the water quality data on their mobile phones instantly. Apart from that, a model called Agile model can be used for this project because it has minimal resource requirements, is suitable for fixed or changing requirements, delivers early partial working solutions. It is a good model for steadily changing environments, and has few rules, making documentation easy. The Internet of Things project also fits these factors. It is thought that the proposed method will be able to aid the government of Malaysia in closely monitoring the physical characteristics of water quality and indirectly reducing the problems caused by water pollution. As a result, sustaining healthy fish populations and adequate supplies for human consumption as well as support positive economic growth through fish farming industry.

The cost of implementing water quality monitoring for fish farming in Malaysia varies depending on several factors such as the scale of the fish farm, the type of monitoring equipment and technology used, the frequency of monitoring, and the specific parameters to be measured. The monitoring equipment such as water quality sensors, data loggers, and monitoring probes can vary significantly depending on their sophistication and accuracy whereas the high-quality sensors tend to be more expensive by providing more reliable data. Besides that, some investment in data management and systems to collect and monitor is also required. The cost of these systems can vary based on their complexity and features.

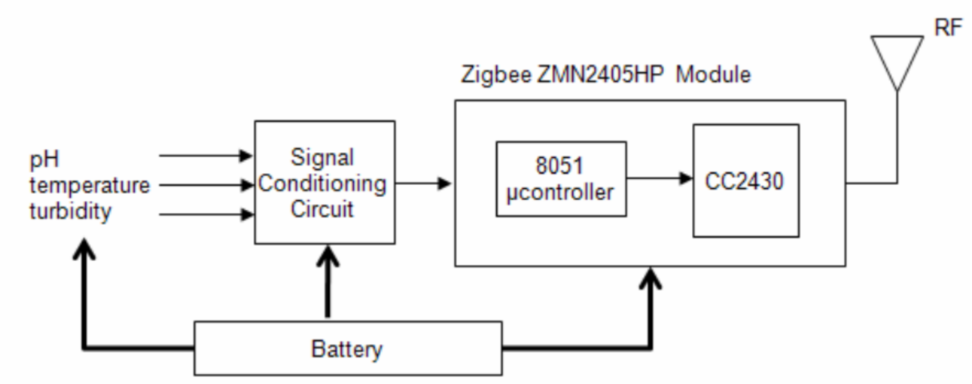

FIGURE 6. Block Diagram of WSN system

Source: Sugapriyaa et al. (2018)

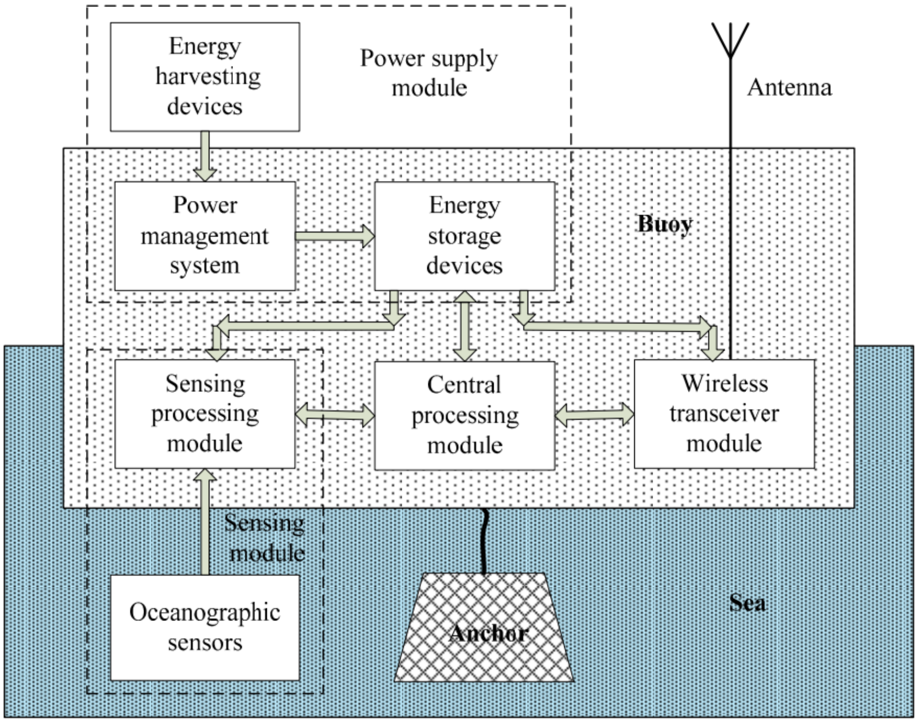

FIGURE 7. Workflow of Sensors Communication

Source: Xu et al. (2014)

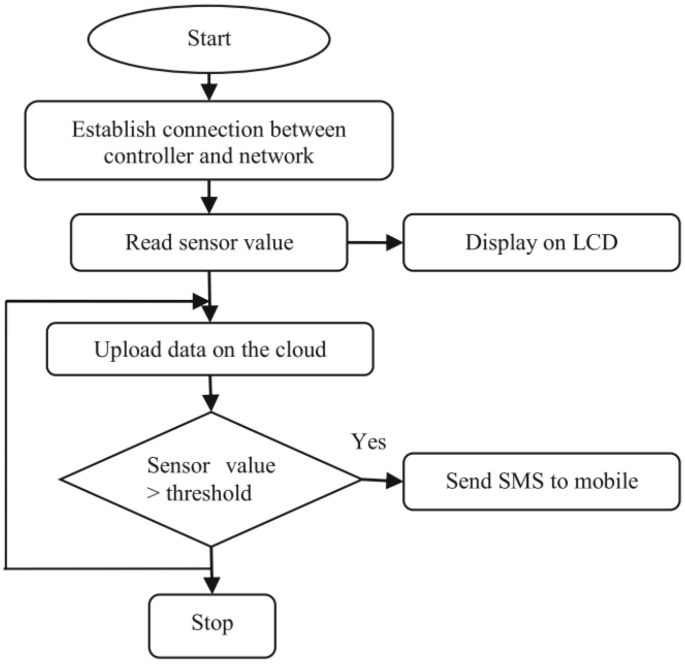

FIGURE 8. The water quality monitoring system flow with IoT
Source: Geetha & Gouthami (2016)

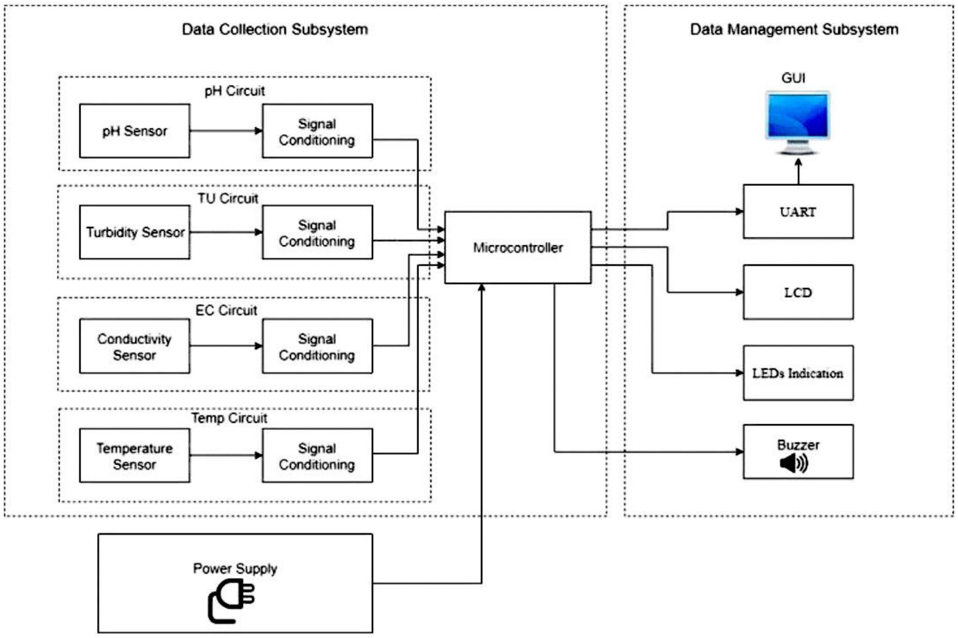

FIGURE 9. The block diagram of the Water Quality Monitoring System

Source: Osman et al. (2018)

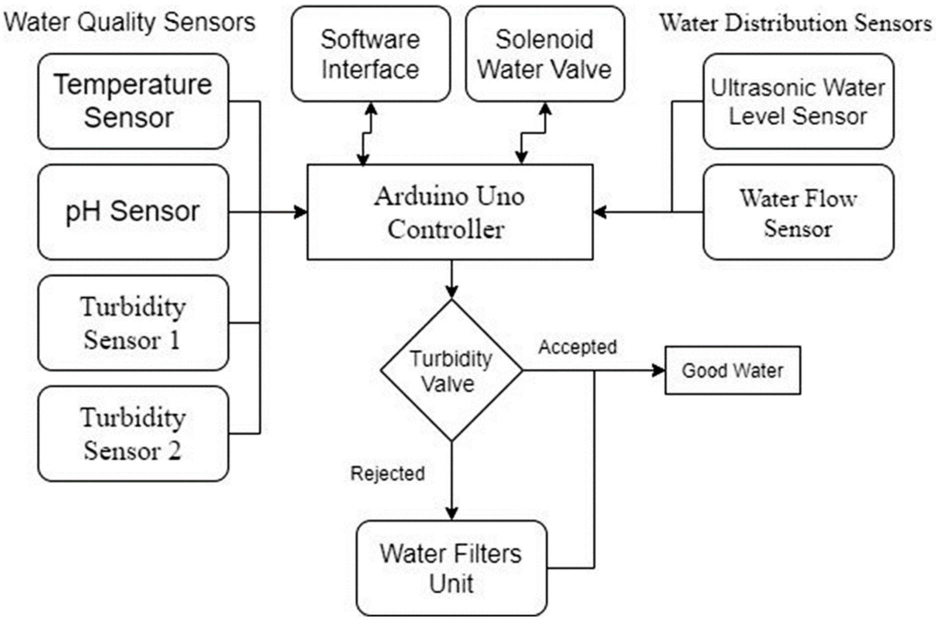

FIGURE 10. The Block Diagram of the Water Quality Monitoring System includes Filter

Source: AlMetwally et al. (2020)

CONCLUSION

The aquaculture sector in Malaysia is expanding quickly. Sectors, including freshwater pond and marine cage cultures, have rapidly expanded. It has been established that Malaysia's cage culture technology for raising fish is technically and economically feasible. Cage culture businesses have already been developed in this nation by the private and semi-governmental sectors in growing numbers. In summary, the dynamic landscape of cage aquaculture in Malaysian coastal regions demands a holistic approach that balances economic growth with environmental stewardship. The research highlights that the adoption of innovative water quality management technologies, coupled with regulatory reforms and collaborative efforts among stakeholders, holds the key to realizing the full potential of cage aquaculture in Malaysia. By addressing these challenges and capitalizing on the opportunities presented, Malaysia can further establish itself as a leader in sustainable and responsible aquaculture practices, safeguarding both its coastal ecosystems and the prosperity of its aquaculture industry for generations to come. Overall, the prospect for the Malaysian aquaculture industry's future growth is positive, but careful planning, strong institutional support, and alluring finance and incentive programs are still necessary. Cage fish farming in Malaysia is vital for economic growth, providing a source of income and food for local communities. It is important to ensure that farming practices are sustainable and environmentally responsible for protecting the long-term health of the marine ecosystem.

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DECLARATION OF COMPETING INTEREST

None

REFERENCES

N. A. D. P. 2021. National strategic plan for sustainable aquaculture development 2030. https://assets.gov.ie/232127/f033aabf-85f6-4d3f-84a0-6e4392ef52c5.pdf

Ahmed, M.M., Ismail, A., & Zulkifli, S.Z. 2020. Geochemical speciation of vanadium and nickel from selected mangrove areas along the west coast of Peninsular Malaysia. *Poll Res* 39 (4): 886-891

AlMetwally, S. A. H., Hassan, M. K., & Mourad, M. H. (2020). Real time internet of things (IoT) based water quality management system. *Procedia CIRP* 91: 478-485.

Alongi, D., Chong, V., Dixon, P., Sasekumar, A., & Tirendi, F. 2003. The influence of fish cage aquaculture on pelagic carbon flow and water chemistry in tidally dominated mangrove estuaries of peninsular Malaysia. *Marine Environmental Research* 55(4): 313-333.

Asmal, I., Syarif, E., Amin, S., & Walenna, M. A. 2022. The impact of the environment and people's attitudes on greywater management in slum coastal settlements. *Civil Engineering Journal (Iran) 8*(12): 2734–2748. https://doi.org/10.28991/CEJ-2022-08-12-05

Boyd, C. E. 2004. Farm-level issues in aquaculture certification: Tilapia. Report commissioned by WWF-US in, 1-29.

Chor, W.-K., Lai, T.-Y., Mathews, M. M., Chiffings, T., Cheng, C.-W., Andin, V. C., Loh, J.-Y. 2022. Spatial Analysis for Mariculture Site Selection: A Case Study of Kukup Aquaculture Zones in the Peninsula of Malaysia. *Frontiers in Marine Science* 751.

Chou, L. M. 2006. Marine habitats in one of the world's busiest harbours. In The environment in Asia Pacific harbours (pp. 377-391): Springer.

Das, B., & Jain, P. 2017. Real-time water quality monitoring system using Internet of Things. Paper presented at the 2017 International conference on computer, communications and electronics (Comptelix).

Devi, P. A., Padmavathy, P., Aanand, S., & Aruljothi, K. 2017. Review on water quality parameters in freshwater cage fish culture. *International Journal of Applied Research* 3(5): 114-120.

Din, Z., & Ahamad, A. 1995. Changes in the scope for growth of blood cockles (Anadara granosa) exposed to industrial discharge. *Marine Pollution Bulletin* 31(4-12): 406-410.

Environment, D. o. 2011. Malaysia Marine Water Quality Criteria and Standard. Retrieved from https://www.doe.gov.my/portalv1/wp-content/uploads/2019/04/BOOKLET-BI.pdf

Fisheries, D. o. 2020. 2020 Annual Fisheries Statistics - Volume 1 (Aquaculture). Retrieved from https://www.dof.gov.my/en/resources/i-extension-en/annual-statistics/

Geetha, S., & Gouthami, S. 2016. Internet of things enabled real time water quality monitoring system. *Smart Water* 2(1): 1-19.

Hai, N. 2015. The use of probiotics in aquaculture. *Journal of Applied Microbiology* 119(4): 917-935.

Hasim, Koniyo, Y., & Kasim, F. 2017. Suitable location map of floating net cage for environmentally friendly fish farming development with geographic information systems applications in lake Limboto, Gorontalo, Indonesia. *AACL Bioflux* 10(2): 254–264.

Holmer, M. 2010. Environmental issues of fish farming in offshore waters: perspectives, concerns and research needs. *Aquaculture Environment Interactions* 1(1): 57-70.

Hossen, M. F., Hamdan, S., & Rahman, M. R. 2015. Review on the Risk assessment of heavy metals in Malaysian clams. *The Scientific World Journal* 905497. doi:10.1155/2015/905497

Iliyasu, A., Mohamed, Z. A., Ismail, M. M., Amin, A. M., & Mazuki, H. 2016. Technical efficiency of cage fish farming in Peninsular Malaysia: A stochastic frontier production approach. *Aquaculture Research* 47(1): 101-113.

Islam, G. M. N., Ta, S. Y., & Kusairi, M. N. 2016. A stochastic frontier analysis of technical efficiency of fish cage culture in Peninsular Malaysia. *SpringerPlus* 5:1127

Ismail, R., Shafinah, K., & Latif, K. 2020. A Proposed model of fishpond water quality measurement and monitoring system based on Internet of Things (IoT). Paper presented at the IOP Conference Series: Earth and Environmental Science.

Kamaruddin, R., & Baharuddin, A. H. 2015. The importance of good aquaculture practices in improving fish farmer's income: A case of Malaysia. *International Journal of Social Economics* 42(12): 1090-1105.

Kamaruzzaman, B., Rina, Z., John, B. A., & Jalal, K. 201). Heavy metal accumulation in commercially important fishes of SouthWest Malaysian coast. *Research Journal of Environmental Sciences* 5(6): 595-602.

Law, E. L. Y., & Law, P. L. 2020. Biochemical oxygen demand, nitrogen, phosphorus and navigational carrying capacities of Bengoh Reservoir for potential aquaculture and recreational developments. *International Journal of Integrated Engineering* 12(9): 224-233.

Loka, J. 2015. Importance of water quality in mariculture. http://eprints.cmfri.org.in/10674/1/14.%20Jayasree%20Loka.pdf

Mahat, N. A., Muktar, N. K., Ismail, R., Abdul Razak, F. I., Abdul Wahab, R., & Abdul Keyon, A. S. 2018. Toxic metals in Perna viridis mussel and surface seawater in Pasir Gudang coastal area, Malaysia, and its health implications. *Environmental Science and Pollution Research* 25(30): 30224-30235. doi:10.1007/s11356-018-3033-8

Mahboob, S. 2013. Environmental pollution of heavy metals as a cause of oxidative stress in fish: a review. *Life Sci. J*, 10: 336-347.

Malaysia, D. o. F. 2009. Code of Practice for Aquaculture in Malaysia. https://www.sirimsts.my/wp-content/uploads/2022/10/SIRIM-DOF-MFF_std.pdf

Malaysia, D. o. F. 2019. Statistik Akuakultur 2018. http://www.dof.gov.my/index.php/pages/view/2118

Mohamat-Yusuff, F., Yun, L. S., Wan, E. C. K., & Zulkifli, S. Z. 2015. Profile of heavy metals level in catfish (Hexanematichthys sagor) and green mussel (Perna viridis) from Kong Kong Laut, Johor Straits. *Acta Biol Malaysia* 4: 46-50.

Muhammad, M. Z. 1993. Seed production of marine fish in Malaysia. Paper presented at the Proceedings of the Aquaculture Workshop for SEAFDEC/AQD Training Alumni, 8-11 September 1992, Iloilo, Philippines.

Nyanti, L., Hii, K., Sow, A., Norhadi, I., & Ling, T. 2012. Impacts of aquaculture at different depths and distances from cage culture sites in Batang Ai Hydroelectric Dam Reservoir, Sarawak, Malaysia. *World Applied Sciences Journal* 19(4): 451-456.

Ong, F. S., & Ransangan, J. 2017. Assessment of spatial and temporal variations of water quality for future mariculture operation in Ambong Bay, Sabah, Malaysia. Open *Journal of Marine Science* 8(01): 1.

Osman, S. O., Mohamed, M. Z., Suliman, A. M., & Mohammed, A. A. 2018. Design and implementation of a low-cost real-time in-situ drinking water quality monitoring system using arduino. Paper presented at the 2018 International Conference on Computer, Control, Electrical, and Electronics Engineering (ICCCEEE).

Price, C., Black, K. D., Hargrave, B. T., & Morris Jr, J. A. 2015. Marine cage culture and the environment: effects on water quality and primary production. *Aquaculture Environment Interactions* 6(2): 151-174.

Rasin, Z., & Abdullah, M. R. 2009. Water quality monitoring system using zigbee based wireless sensor network. *International Journal of Engineering & Technology* 9(10): 24-28.

Razali, R. M., Rahim, M. A., & Yaacob, K. K. K. 2021. Phytoplankton composition of mariculture area in Sungai Udang, Penang, Malaysia, the northern Strait of Malacca. *Malaysian Journal of Science* 87-104.

Sfakianakis, D. G., Renieri, E., Kentouri, M., & Tsatsakis, A. M. 2015. Effect of heavy metals on fish larvae deformities: A review. *Environmental Research* 137: 246-255. doi:https://doi.org/10.1016/j.envres.2014.12.014

Stoliar, O. B., & Lushchak, V. I. 2012. Environmental pollution and oxidative stress in fish. Oxidative stress-environmental induction and dietary antioxidants, 131-166.

Sugapriyaa, T., Rakshaya, S., Ramyadevi, K., Ramya, M., & Rashmi, P. 2018. Smart water quality monitoring system for real time applications. *Int. J. Pure Appl. Math*. 118(20): 1363-1369.

Suratman, S., Hussein, A., Tahir, N. M., Latif, M. T., Mostapa, R., & Weston, K. 2016. Seasonal and spatial variability of selected surface water quality parameters in Setiu wetland, Terengganu, Malaysia.

Toha, T. 2008. The Influence of Seasonal Changes on Physico-Chemical Characteristics of Seawater in Sepangar and Gaya Bays, Sabah. Universiti Malaysia Sabah,

VC, C., & Sasekumar, A. 2002. Fish communities and fisheries of Sungai Johor and Sungai Pulai Estuaries (Johor, Malaysia). *Malayan Nature Journal* 56(3): 279-302.

Wurts, W. A., & Durborow, R. M. 1992. Interactions of pH, carbon dioxide, alkalinity and hardness in fish ponds.

Xu, G., Shen, W., & Wang, X. 2014. Applications of wireless sensor networks in marine environment monitoring: A survey. *Sensors* 14(9): 16932-16954.

Yap, C. K., Peng, S. H. T., & Leow, C. S. 2019. Contamination in Pasir Gudang Area, Peninsular Malaysia: What can we learn from Kim Kim River chemical waste contamination? *International Journal of Humanities and Education Development (IJHED)* 1(2): 84-87. https://www.theshillonga.com/index.php/jhed/article/view/17

Yusoff, A. 2015. Status of resource management and aquaculture in Malaysia. Proceedings of the International Workshop on Resource Enhancement and Sustainable Aquaculture Practices in Southeast Asia 2014 (RESA) (pp. 53-65). Tigbauan, Iloilo, Philippines: Aquaculture Dept., Southeast Asian Fisheries Development Center.

Antonson, H., Ahlström, C., Mårdh, S., Blomqvist, G., & Wiklund, M. 2014. Landscape heritage objects' effect on driving: A combined driving simulator and questionnaire study. *Accident Analysis and Prevention* 62(1): 168-177.